Engineering Bulletin

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PROPORTIONAL REVERSE BASE CURRENT DRIVE CIRCUIT

There are several techniques for reducing the transistor switching losses in high voltage switching applications: turn-on times can be minimized by driving the base with a fast rise-time, relatively high current pulse and storage times can be reduced by means of a Baker clamp or proportional feedback current transformer. But, these approaches are counter productive as the base overdrive increases the storage time and for the second approach, by reducing the drive, the turn-on time increases.

Turn-off losses can also be reduced by increasing the transistor's off-bias voltage $V_{BE(off)}$ and/or reverse base current I_{B2}. The fall time t_f will be reduced with increasing I_{B2} (as will the storage time t_s) but only up to a point where the device will still operate as a transistor. When the peak reverse bias current approaches the magnitude of the collector current at turn-off (the emitter current approaches zero), transistor action ceases, and the fall time now measured is the recovery time of the collector-base junction, which for many high voltage switching transistors can result in slower fall times. This is illustrated in the turn-off times versus I_{B2} curves of Figure 1 where the t_f curve inflects upward when I_{B2} is approximately equal to I_C. This condition becomes more pronounced in applications where the collector load varies but the base drive remains a constant.

To ensure that t_f remains low would require that I_{B2} always be less than the changing I_C, thus the need for a

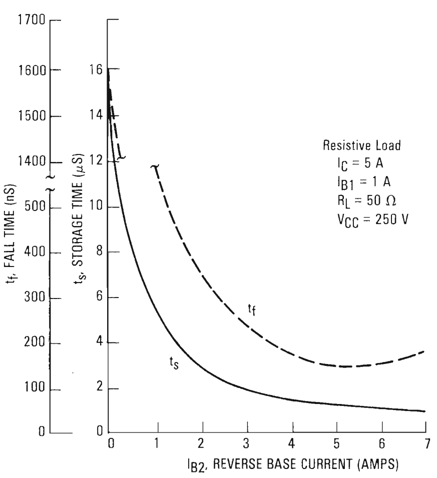

Figure 1
Typical Turn Off Times as a Function of Reverse Base Current I_{B2}

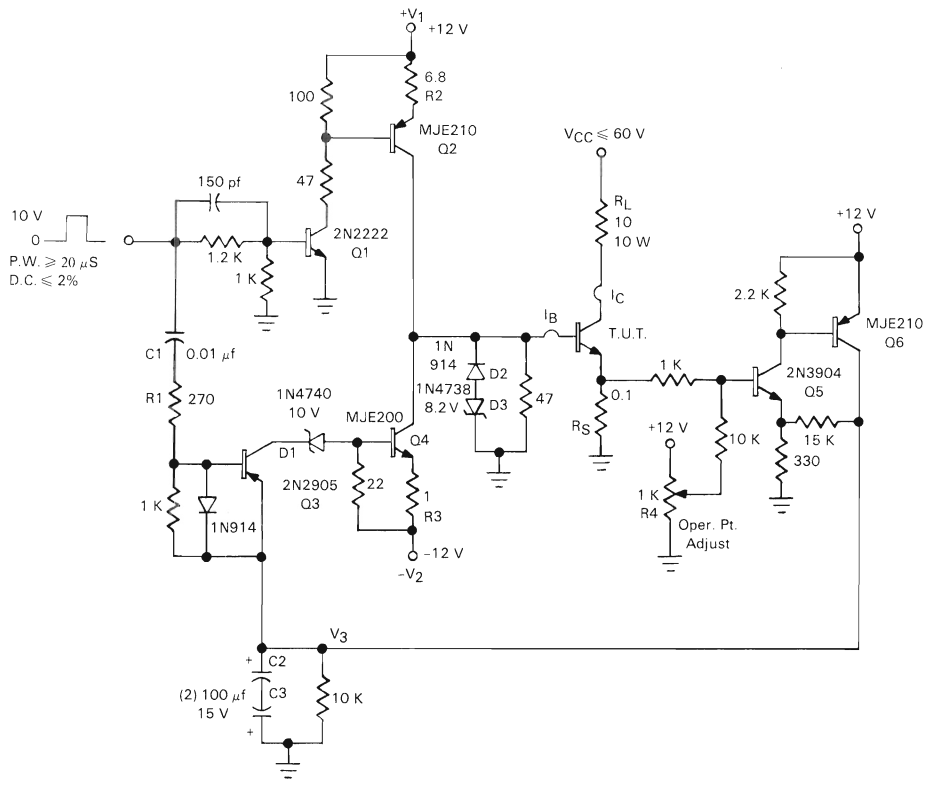

Figure 2
Proportional I_{B2} Drive Circuit

proportional reverse base current drive circuit (Figure 2). This circuit consists of the I_{B1} and I_{B2} current generators driving the transistor under test (T.U.T.) and a feedback loop, sensing I_C and controlling the I_{B2} generator to be a function of I_C.

Forward base current I_{B1} is generated by turning on the NPN transistor Q_1 with a positive going input pulse. This stage then turns on the constant current PNP generator Q_2 (as set by V_{E2} and R_2), supplying I_{B1} to T.U.T. Reverse base current is derived by differentiating the input pulse with the R_1C_1 network. The generated negative going pulse, coincident with the trailing edge of the input pulse, then turns on PNP transistor Q_3 and the following NPN constant current I_{B2} generator Q_4. Thus, this generator will be on for the time immediately following the input pulse, approximately 10μs for the values shown, allowing the stored charge to be swept out of the T.U.T. collector-base region. The magnitude of I_{B2} is set by the base voltage V_{B4} (and thus the emitter voltage) of Q_4 and R_3. By varying V_{B4}, I_{B2} can be varied. This can be accomplished at a low power stage by varying the supply voltage V_3 to Q_3. To allow greater I_{B2} control, zener diode D_1 is used to couple the full change of V_3 to the base of Q_4. To prevent avalanching the base-emitter of the T.U.T., zener diode D_3 and blocking diode D_2 are used.

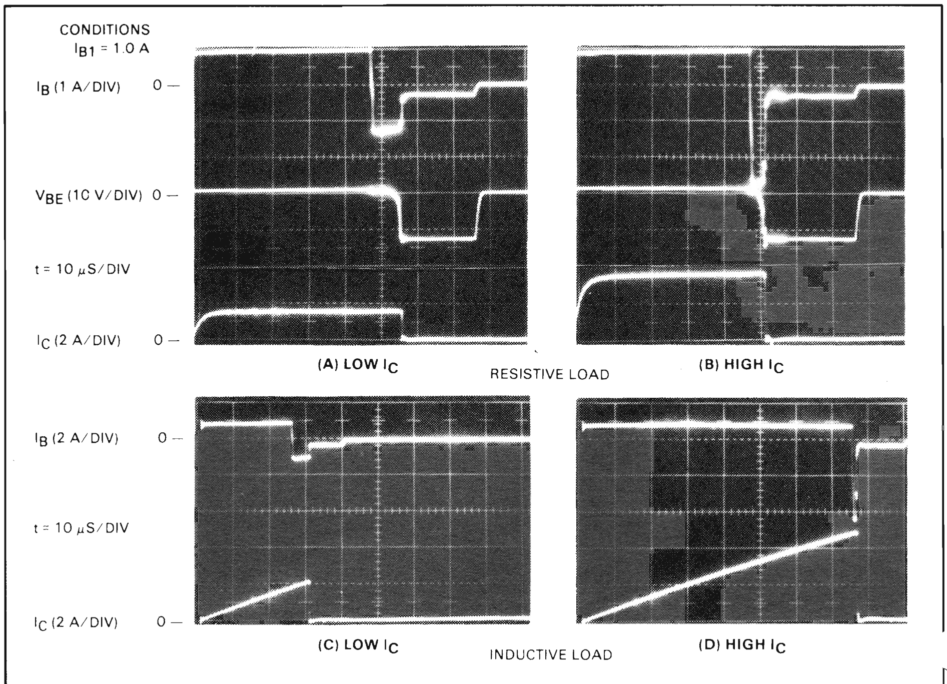

Figure 4
Proportional I_{B2} Control of a 2N6250

FIGURE 3(A) — RESISTIVE LOAD FALL TIME

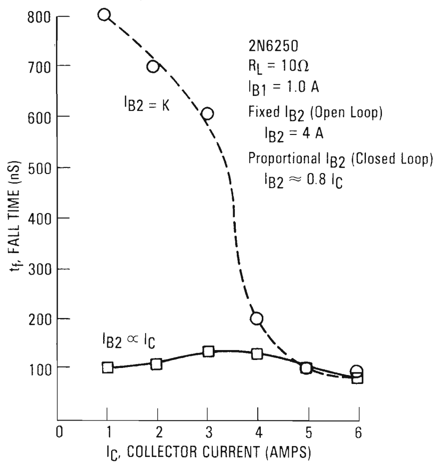

FIGURE 3(B) — RESISTIVE LOAD STORAGE TIME

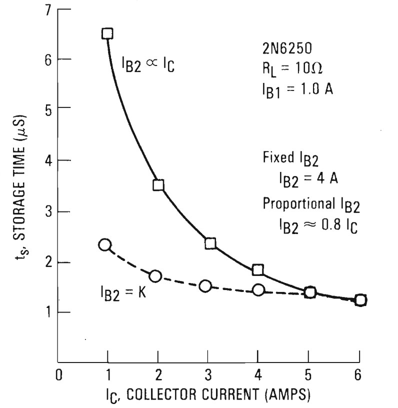

Figure 3
Turn Off Times with Fixed and Proportional Reverse Base Current I_{B2}

Collector current (in reality, emitter current) is sensed by resistor R_S with the resultant voltage fed to the input of the two transistor, non-inverting, control amplifier (Q_5 and Q_6). The output of Q_6, filtered by back-to-back capacitors C_2 and C_3 in a non-polarized configuration, is thus the variable supply voltage V_3 for the I_{B2} current generator. Potentiometer R_4 sets the operating point and for T.U.T. collector current range of from 1 to 6A resulted in a V_3 of from about −0.6V to +4.8V respectively. This variation in V_3 produced an I_{B2} of about 0.8A to 4.8A respectively (about 80% of I_C), illustrating the proportional control.

The effects on a 2N6250 resistive load fall times with the closed loop proportional drive and an open loop, fixed I_{B2} are shown in the curves of Figure 3(A). These curves were derived with a constant I_{B1} of 1.0A and the collector current varied between 1 and 6A by varying the V_{CC} supply from about 10V to 60V (R_L = 10 ohms). For the fixed I_{B2} case, the peak reverse base current was set for 4A. The proportional control I_{B2} was also normalized to 4A when I_C was 5A. Thus all collector currents below 5A for the open loop case show a high t_f (due to I_c being less than I_{B2}), varying from about 800ns at I_c of 1A to about 100ns at 5A. The proportional I_{B2} condition resulted in a relatively constant t_f of about 100ns, decreasing to about 70ns at an I_c of 6A when I_{B2} was 4.8A.

Using a clamped inductive load produced similar results; the open loop fall-times varied from 500ns down to about 90ns for I_c's between 1 to 6A and the proportional drive yielded t_{fi}'s of about 25ns to 100ns respectively.

The photographs of the base and collector currents with proportional I_{B2} control for both a resistive load and a clamped inductive load are shown in Figures 4(A) through (D). Also illustrated in the photos of Figures 5(A) through (C) are the inductive waveforms for a fixed I_{B2}. Note the I_{B2} feedthrough on the collector current waveform of Figure 5(C) when the peak collector current (I_{CM}) is less than I_{B2}. In addition to distorting the collector current ramp, increased turn-off switching stresses (RBSOA) would also result. For high I_c conditions (Figure

5(B)), where I_c exceeds I_{B2}, no feed-through is evident.

Although fall-time remained low and relatively constant with proportionals I_{B2}, there is a trade-off in t_s as shown in the storage time curves of Figure 3(B). Since storage time is inversely proportional to reverse bias, the constant and high I_{B2} of the open loop case (4A in this example) will produce lower t_s at low collector currents than the proportional drive case where I_{B2} is a variable (about 80% of I), but low. At higher collector currents, however, the proportional drive will result in lower t_s as now, its I_{B2} is greater than the fixed I_{B2} open loop case.

By extension, one might think that the storage time could also be reduced through proportional forward base current I_{B1} drive, thus minimizing the overdrive. A circuit using a dual op-amp was designed to control both the I_{B2} current generator (by varying V_3) and the I_{B1} generator (controlling $+V_1$). Fall time did improve somewhat (100ns compared to 150ns at I_c of 2A) but the storage time remained about the same due to the resultant lower I_{B2}. It was felt that the lower t_f did not justify the additonal circuitry.

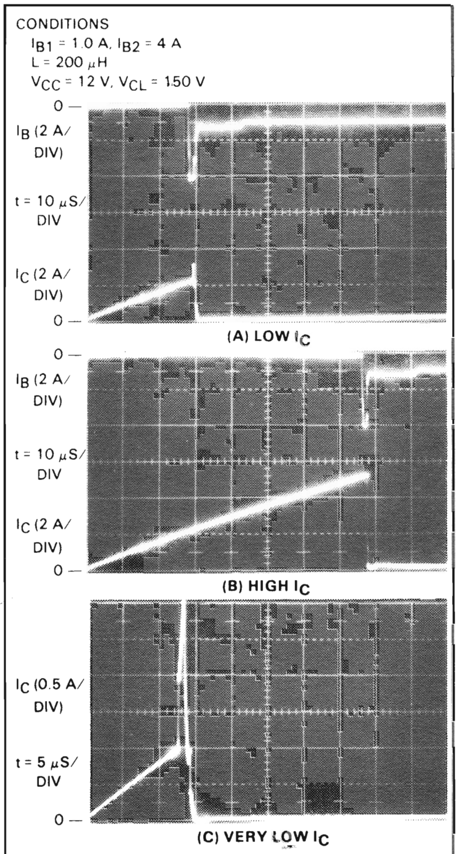

Figure 5
Constant I_{B2} Control of a 2N6250 with and Inductive Load

For those applications where the reverse base voltage $V_{BE(off)}$ is used to decrease the turn off switching times (Figure 2, R_3 is zero), the supply voltage $-V_2$ can then be controlled in a manner similar to the current control case. An additional power stage would however be required in the control amplifier to drive this higher current circuit. Then, by using the $V_{BE(off)}$ versus I_{B2} reverse input characteristics that are illustrated in many Designers Data Sheets, the required translation can be made.

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